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THE SUBTIDAL FOULING ORGANISMS OF THE CALLIOPE RIVER AND AUCKLAND CREEK, CENTRAL QUEENSLAND

P. SAENGER*
W. STEPHENSON+
and
J. MOVERLEY*

ABSTRACT

The fouling organisms of Calliope River and Auckland Creek have been investigated to determine the most abundant and recurrent macrofouling species, and their succession on newly exposed surfaces. Short- and long-term test plates have been used at three localities since May 1975, and data to May 1977 are analysed here.

Forty-seven species were found on the short-term plates. Thirteen were sessile and used in numerical analyses. Sites 2 and 3 (Calliope River) differed from Site 1 (Auckland Creek) by: the number of species; paired *t*-tests of species occurrence; and the mean number of individuals of each species. These differences are presumed to reflect physical disturbance at Site 1. Only three species *(Balanus, Ficopomatus* and *Electra)* occurred consistently on the short-term plates. Optimal wavelengths of the 5 species which showed significant periodicity in settlement were determined and compared with periodicities in temperature, chlorinity and rainfall. All had significant relationships with temperature, 3 with chlorinity and 0 with rainfall. Algal biomass also showed a much closer relationship to temperature than to chlorinity.

The long-term plates indicated that a 'pioneer' phase is gradually (after 3–11 months) replaced by a 'climax' phase, characterized by *Crassostrea, Modiolus, Balanus* and *Ficopomatus.* A mosaic of the 'pioneer' and 'climax' phases is the common condition found on old plates and on naturally occurring substrates in the study area.

Apart from their obvious economic importance, fouling organisms provide a measure of the extent of pollution for they must remain exposed to the physical conditions which surround them (McCain 1975). Since April 1975, three sets of artificial-substrate samplers have been placed in the Calliope River (2) and Auckland Creek (1) to determine (a) the most abundant and recurrent macrofouling organisms, their settling periods and factors associated with settlement, and (b) the natural sequence of colonisation and development on newly exposed surfaces.

Various numerical techniques have been used to analyse the data, and a novel technique has been developed by one of us (W.S.), which allows the rapid determination of optimal wavelengths of periodic species.

THE STUDY AREA

The study area (Fig. 1) comprises the Calliope River and Auckland Creek which flow into Port Curtis. Draining an upland of mostly argillaceous rock, the Calliope River carries a large stream sediment load of predominantly mud (Conaghan 1966).

Climatically the area is subtropical with a mean annual rainfall (81 years) of 1011 mm falling mostly during December to March. Mean monthly rainfall and mean monthly river flow volume in the Calliope River are given in Fig. 2 for the duration of the study period.

Water temperatures in the Calliope River during the study period ranged from 16·2°C in July 1976 to 31·2°C in December 1976. Salinities for the same period showed concentrations of 37·94°/oo during winter and 6·53°/oo during the wetter months. Turbulent flow in the rivers (the tidal range is up to 4·2 m) results in generally mixed water and stratification is slight.

* Scientific Services Branch, Queensland Electricity Generating Board, Brisbane.
+ Zoology Department, University of Queensland.

SAMPLING METHODS

Each artificial-substrate sampler consists of a stainless steel rod (diameter 9·5 mm) on which are placed six sandblasted glass plates 30 × 30 cm. The plates are separated by PVC spacers 6 cm long. The entire sampler is weighted by a small drum filled with concrete and it is held 1·5 m above the bottom by a small buoy attached immediately above the uppermost plate. A second buoy at the surface ensures relocation.

Glass plates were originally used but breakages were frequent. After preliminary tests, these were replaced by roughened white perspex plates of identical dimensions.

SHORT-TERM PLATES

At least one plate was renewed on each sampler at approximately monthly intervals. Each surface of the fouled plates was divided into 25 cm^2 squares and in eight selected squares on each surface, all organisms were counted. Of the eight squares counted, two included one or two edges while the remaining six were away from edges. Plates from Site 2 with algae on the upper surface were air-dried, and the dried algal biomass was determined.

LONG-TERM PLATES

Long-term plates, lifted at various irregular intervals, were transported to the laboratory in water-proofed containers and all organisms were counted on both surfaces of each plate.

RESULTS

SHORT-TERM PLATES

During the 24 months of this study, a total of 47 species were found on these plates (Table 1). Of these species, thirteen were algae growing on the

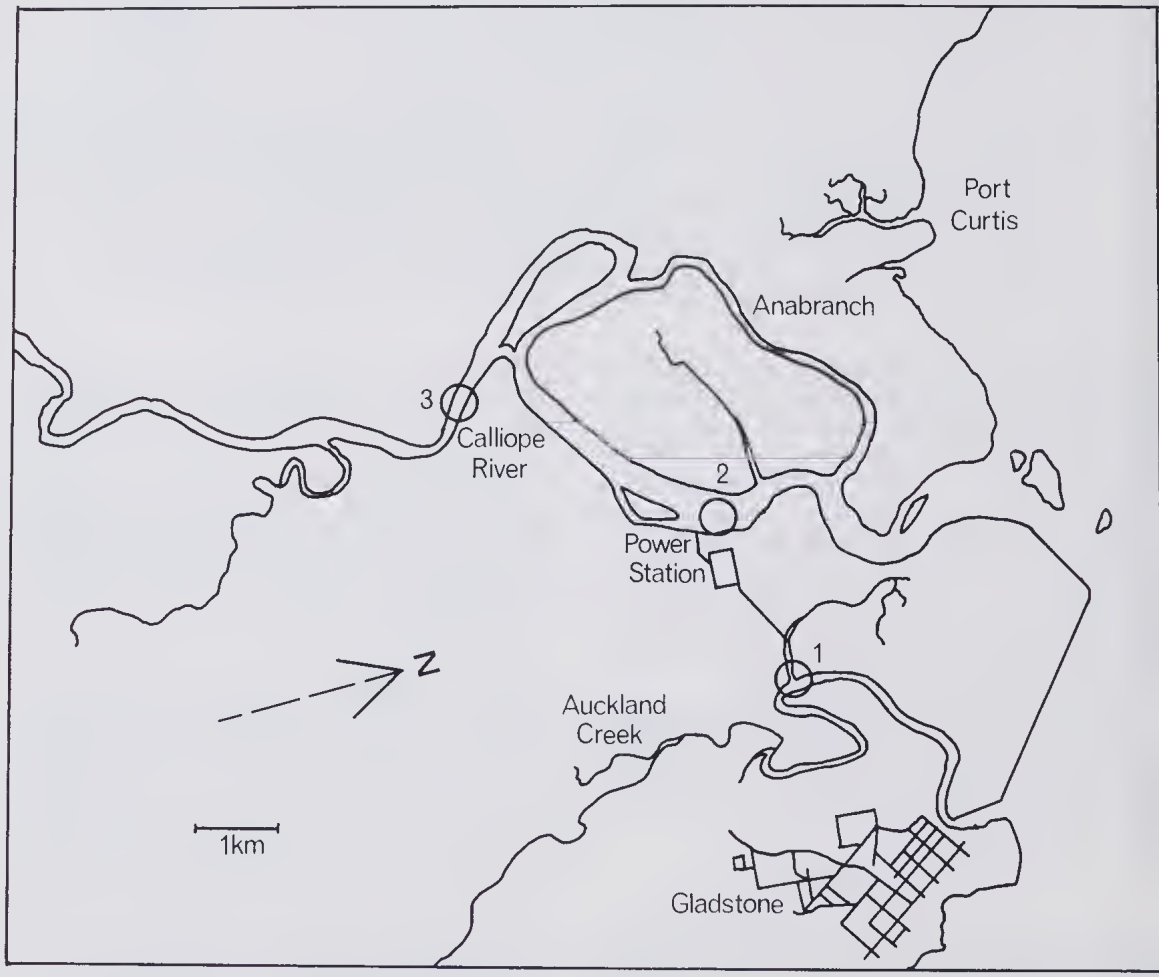

FIG. 1: Location of artificial-substrate samplers: Sites 1, 2 and 3.

upper surface of the plates at Site 2, one *(Obelia longicyatha)* was found only once on the upper surface of the plates at Site 3, and twenty-one were non-sessile species. The remaining twelve sessile species were used in the numerical analyses. Subsequent reference to species is generally by generic name where known, or by code number (Table 1).

TABLE 1: SPECIES LIST. SHORT-TERM PLATES

Species	Systematic Position	Code No.
SESSILE SPECIES		
Balanus amphitrite Darwin	Cirripedia, Crustacea	1
Ficopomatus uschakovi Pillai	Serpulidae, Polychaeta	2
Bugula cf. *stolonifera*	Bryozoa	3
Dryopoides sp.	Amphipoda, Crustacea	4
Electra cf. *anomala*	Bryozoa	5
Hippodiplosia sp. A	Bryozoa	6
Crassostrea cucullata (Born.)	Ostraedia, Bivalvia	7
Ascidia sydneyensis Stimpson	Tunicata	8
Tubularia crocea (Agassiz)	Hydrozoa, Coelenterata	9
ascidian I	Tunicata	10
ascidian III	Tunicata	11
Plumularia sp.	Hydrozoa, Coelenterata	12
Obelia longicyatha Allmann	Hydrozoa, Coelenterata	
Bryopsis indica Gepp and Gepp	Bryopsidaceae, Chlorophyta	
Hormidium subtile (Kuetz.) Heering	Ulotrichaceae, Chlorophyta	
Rhizoclonium sp.	Cladophoraceae, Chlorophyta	
Giffordia mitchellae (Harvey) Hamel	Ectocarpaceae, Phaeophyta	
Sporochnus comosus C. Agardh	Sporochnaceae, Phaeophyta	
Callithamnion sp.	Ceramiaceae, Rhodophyta	
Ceramium cliftonianum J. Agardh	Ceramiaceae, Rhodophyta	
Hypoglossum sp.	Delesseriaceae, Rhodophyta	
Polysiphonia variegata (C. Ag.) Zan.	Rhodomelaceae, Rhodophyta	
Ptilocladia sp.	Ceramiaceae, Rhodophyta	
Lophocladia harveyi (Kuetz.) Schmitz	Rhodomelaceae, Rhodophyta	
Soliera robusta (Grev.) Kylin	Solieriaceae, Rhodophyta	
Spermothamnion sp.	Ceramiaceae, Rhodophyta	
ASSOCIATED SPECIES		
Ceradocus sp.	Amphipoda, Crustacea	
Paraphoxus sp.	Amphipoda, Crustacea	
amphipod II	Crustacea	
amphipod V	Crustacea	
caprellid I	Amphipoda, Crustacea	
Macrobrachium sp.	Macrura, Crustacea	
Parapandalus sp.	Macrura, Crustacea	
Rhynchocinetes sp.	Macrura, Crustacea	
Hippolytidae sp. III	Macrura, Crustacea	
Alpheus sp.	Macrura, Crustacea	
Paracerceis sp.	Isopoda, Crustacea	
Xanthidae sp. I	Brachyura, Crustacea	
Hyastenus sp.	Brachyura, Crustacea	
Charybdis helleri (M.-Edwards)	Brachyura, Crustacea	
Lutjanus fulviflamma (Forskal)	Lutjanidae, Pisces	
Prionobutis microps (Weber)	Eleotridae, Pisces	
Drombus palackyi (Jordan and Seale)	Gobiidae, Pisces	
Omobranchus punctatus (Valenciennes)	Blenniidae, Pisces	
Omobranchus ?germaini (Sauvage)	Blenniidae, Pisces	
Redigobius chrysosoma (Bleeker)	Gobiidae, Pisces	

Data on species from monthly plates comprised estimated numbers of individuals, except for: algae (estimated by dry weight); bryozoans (counted as colonies); and colonial, prostrate organisms. Ascidian III and *Plumularia* were given a surface cover rating (3 = dense; 2 = medium; 1 = sparse; 0 = absent) which was summed and averaged. To bring all data to an equivalent form, these ratings were multiplied by ten and the resultant regarded as numbers of individuals. Hence the data which were analysed are all in meristic (whole number) form. A copy of these raw data has been deposited with the editor.

These data comprise a 12 species × 3 sites × 24 times (t_{1-24}) matrix, although for Site 3, data for t_2, t_{18}, t_{19} and t_{24} were missing due to vandalism and flooding.

In recent analyses (Stephenson and Campbell 1977, Stephenson *et al.* 1977) 3D matrices have been converted into three separate 2D matrices and these have then been classified and/or ordinated. With only three sites, a site

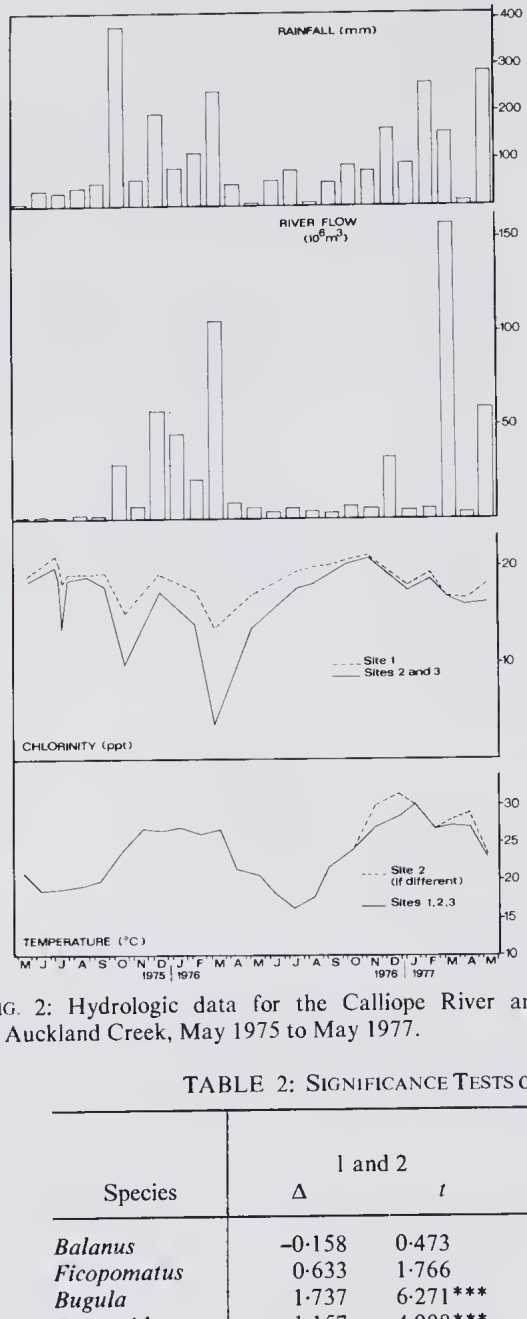

FIG. 2: Hydrologic data for the Calliope River and Auckland Creek, May 1975 to May 1977.

classification is somewhat trivial and differer approaches were used.

INTERSITE COMPARISONS

The following were calculated for each plate: — the number of species present; N — th number of individuals of all species; G — Gleaso diversity; H' — standardised Shannon diversity base 2 and J' — Shannon equitability. Perusal the data suggested that intersite differences wou be most clearly revealed on the S and N value Using times at which all sites were sample paired t tests were performed using the three pai of sites. Only the S values showed any significa differences as follows: between Site 1 (mean 5·8 and site 2 (mean 4·60) significant at 0·01 leve between Site 1 and Site 3 (mean 4·55) aga significant at 0·01 level. Since these tests we performed on raw values without regard f normality of distribution, they should be regarde as rough tests only. However they set Site 1 apa from the others.

The data suggested that the most effecti method of comparing sites would be to opera with individual species using paired t tests. F these tests to be entirely satisfactory, data shou be normally distributed and there should similar variance in the two sets under compariso Attempts were made to normalise the data most cases) by using fractional power transform tions, plotting histograms and making visu judgements. Results suggest a 4·5th root as t most suitable overall transformation and this w used in the t tests and also for later analyses.

TABLE 2: SIGNIFICANCE TESTS OF SPECIES OCCURRENCES AT PAIRED SITES

Species	Pairs of sites compared: 1 and 2 Δ	1 and 2 t	1 and 3 Δ	1 and 3 t	2 and 3 Δ	2 and 3 t
Balanus	–0·158	0·473	–0·183	0·538	–0·025	0·130
Ficopomatus	0·633	1·766	–0·350	1·451	–0·983	2·706*
Bugula	1·737	6·271***	1·966	8·861***	0·229	2·249*
Dryopoides	–1·157	4·098***	–1·054	4·541***	0·103	0·560
Electra	0·548	2·069	0·268	1·210	–0·280	2·179*
Hippodiplosia	0·824	4·461***	0·931	6·469***	0·107	0·725
Crassostrea	0·244	1·375	0·432	1·648	0·188	1·041
Ascidia	0·502	2·578*	0·502	2·578*	—	—
Tubularia	–0·331	1·863	–0·155	0·802	0·176	0·832
ascidian I	0·223	2·164*	0·223	2·164*	—	—
ascidian III	0·478	2·782*	0·478	2·782*	—	—
Plumularia	–0·819	4·240***	–0·648	3·469***	0·173	0·616

* Significant at 0·05 level
** At 0·01 level
*** At 0·001 level

Results of the *t* tests, given in Table 2, show that only three species (*Balanus, Crassostrea* and *Tubularia)* fail to show significant differences between any of the pairs of sites. Table 2 also shows that Sites 2 and 3 have the smallest number (3) of significantly different species viz. *Electra* and *Ficopomatus* which are both lower in Site 2, and *Bugula* which is higher in Site 2. Sites 1 and 2 and Sites 1 and 3 have seven significantly different species.

Further comparisons between sites were made using the mean number of individuals of each species (averaged over the 20 'common' times) — these are given in Table 3. The most useful comparisons involve correlation coefficients which are amenable to significance testing. Spearman rank correlation coefficients between pairs of sites are given in Table 4 together with the Pearson product–moment correlation coefficient based on normally transformed data. From Table 4 it is apparent that there is highly significant similarity between Sites 2 and 3. Based on this, it would be legitimate to fuse Sites 2 and 3 for intertime comparisons but this was not done for three reasons: (a) three species have significantly different populations in the two sites (Table 2), (b) data in Table 3 are averaged over times and hence eliminate possible phase differences between periodic changes and (c) there are difficulties due to the incomplete data at Site 3.

TABLE 3: MEAN NUMBER* OF INDIVIDUALS PER SPECIES PER SITE

Species	Site 1	Site 2	Site 3
Balanus	72·35	164·25	132·60
Ficopomatus	109·85	107·55	241·80
Bugula	68·40	3·90	0·15
Dryopoides	1·75	25·70	13·20
Electra	12·00	4·05	10·75
Hippodiplosia	10·75	3·45	0·70
Crassostrea	17·35	1·00	0·80
Ascidia	7·95	4·15	0
Tubularia	0·90	4·20	1·85
ascidian I	0·35	0	0
ascidian III	3·05	0	0
Plumularia	0	5·55	1·85

* Averaged over 20 times

TABLE 4: INTERSITE COMPARISONS USING CORRELATION COEFFICIENTS DERIVED FROM TABLE 3

Coefficient	Sites compared		
	1 and 2	1 and 3	2 and 3
Spearman	0·257	0·385	0·827**
Pearson	0·499	0·441	0·886**

** Significant at 0·01 level

INTERTIME COMPARISONS

CLASSIFICATION: Stephenson, Williams, and Cook (1974) have noted that hierarchical classification of times by species is likely to give confusing results with time-groups, giving mixtures of seasonality and annuality. Nevertheless a species × times matrix was classified hierarchically for each of the three sites. Those species absent from a given site were eliminated first and one species *(Plumularia)* was also eliminated because it occurred at a single time.

Bray-Curtis dissimilarities were used because these are moderately abundance sensitive, and the data was transformed to avoid giving undue stress to occasional high values. In the past, choice of the transformation has been arbitrary, and the same transformation (usually log $(n+1)$) has been applied prior to entity classification and to attribute classification. Here a series of root transformations from n to $n^{1/8}$ were used on the columns of data (entities = times) and modal root transformations which reduced the moment coefficient of skewness to a predetermined level were sought. Using a coefficient of 0·50 gave an entities transformation, and repeating with rows of data (attributes = species) gave an attribute transformation. It should be noted that the latter was less stringent.

For Site 1 the entity transformation was a 4th root and the attribute transformation a square root. Entities were classified by using the Bray-Curtis dissimilarity on 4th rooted data followed by group-average sorting and the dendrogram is given in Fig. 3a. Attributes were classified by using the Bray-Curtis on square rooted data, followed by standardisation by attribute totals, then group-average sorting. The resultant dendrogram is shown in Fig. 3b.

Considering attributes first, six species groups were selected, shown X on Fig. 3b. The only sizeable and moderately coherent group contains *Balanus, Ficopomatus, Bugula, Electra* and *Hippodiplosia*. The entity dendrogram was resolved into eight time groups shown as X in Fig. 3a. With the exception of three times (t_{12-14}) all groups contained sequential times; the only grouping with any hint of seasonality is the right one in Fig. 3a which groups April to May 1976 with Jan. to April 1977.

Dryopoides and *Ascidia* characterise $t_{18,19}$; *Tubularia* $t_{15,16}$; *Crassostrea* $t_{12,13,21-24}$; and ascidian II t_{9-14}. In other words five of the eleven species are best regarded as intermittents. The

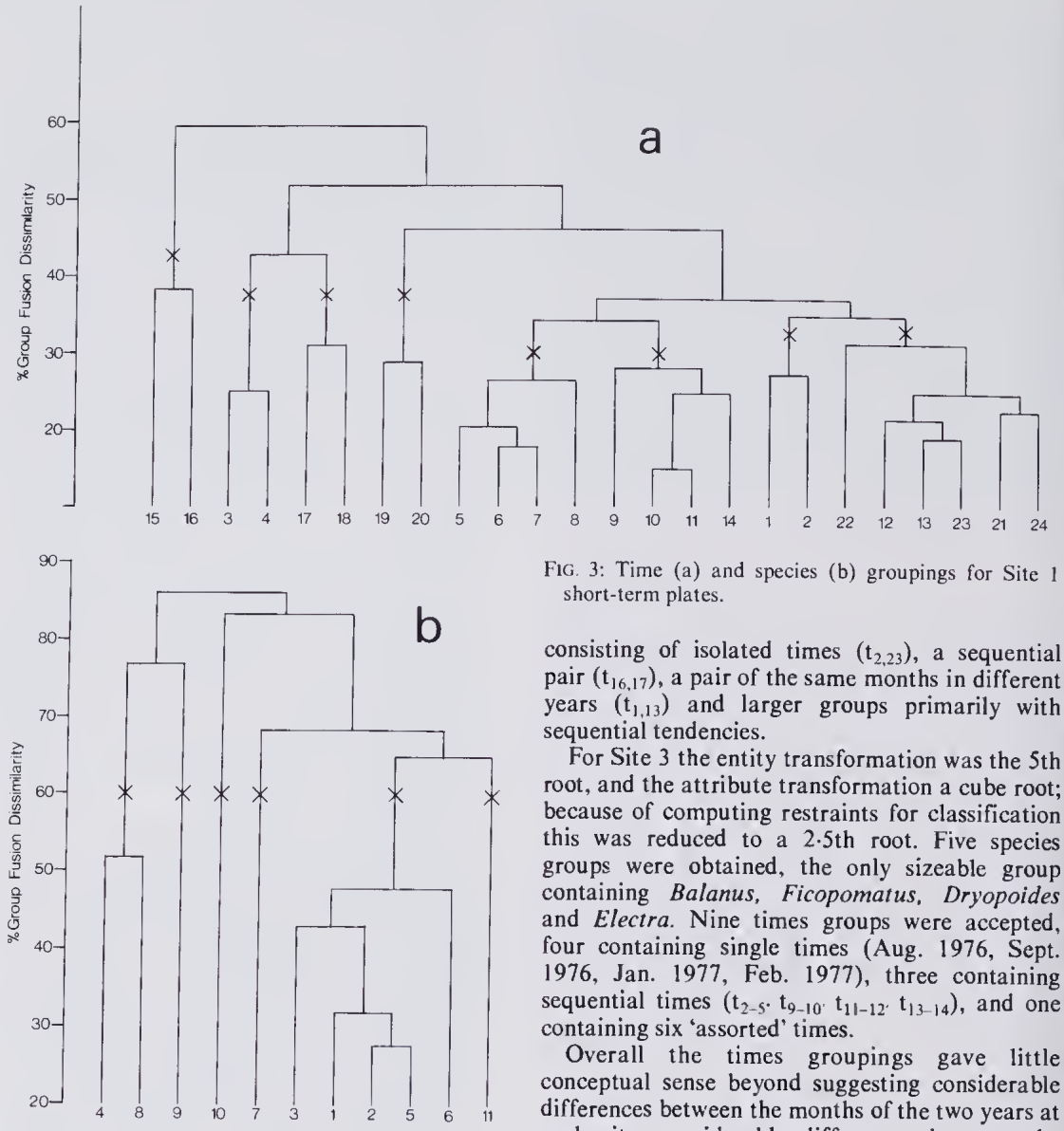

FIG. 3: Time (a) and species (b) groupings for Site 1 short-term plates.

more abundant species — the five listed earlier — are best regarded as recurrents and the clustering technique fails to distinguish any marked times changes in these species.

Results on the other sites were broadly similar and the dendrograms are omitted. For Site 2 the entity transformation was *ca.* 4·5th root, and the attribute transformation a square root; for classification 4th root and square root were used respectively. Six species groups were obtained, with the only sizeable group containing *Balanus, Ficopomatus, Dryopoides, Electra* and *Plumularia.* Eight times groups were accepted consisting of isolated times ($t_{2,23}$), a sequential pair ($t_{16,17}$), a pair of the same months in different years ($t_{1,13}$) and larger groups primarily with sequential tendencies.

For Site 3 the entity transformation was the 5th root, and the attribute transformation a cube root; because of computing restraints for classification this was reduced to a 2·5th root. Five species groups were obtained, the only sizeable group containing *Balanus, Ficopomatus, Dryopoides* and *Electra.* Nine times groups were accepted, four containing single times (Aug. 1976, Sept. 1976, Jan. 1977, Feb. 1977), three containing sequential times (t_{2-5}, t_{9-10}, t_{11-12}, t_{13-14}), and one containing six 'assorted' times.

Overall the times groupings gave little conceptual sense beyond suggesting considerable differences between the months of the two years at each site, considerable differences between the different sites and an overall tendency to group sequential times. Only three species are consistently in the same group and these are the three most abundant species — *Balanus, Ficopomatus* and *Electra.*

ANALYSES OF PERIODICITY: Stephenson (1978) has previously used autocorrelation coefficients to determine the wavelength of the optimal cycle in the data, and multiple regression to quantify the importance of a selected wavelength. This was felt to be preferable to the more standard approach using power-curve spectra for the following reasons: (a) power-curve spectra available through

standard computer programmes have frequency as the dependent variable; hence wavelength is scaled reciprocally, giving wide spacing in areas of interest and (b) quantification of the variance is not readily effected and in effect, requires multiple regression.

Given any wavelength *(T)*, the proportion of the total sum of squares accounted for by the regression (R^2), can be derived by multiple regression. If the chosen wavelength is the predominant one in the system then R^2 will be maximal. By 'scanning' through a series of wavelengths and plotting values of R^2, a different form of spectrum — here called a variation spectrum — can be obtained, the advantages being: (a) wavelength not frequency is the dependent variable. This gives the desired equal spacing when wavelength is the main interest. (b) scanning intervals can be adjusted to give fine resolution in wavebands of especial interest, an important advantage over autocorrelations. (c) R^2 values and F values for significance testing are readily interchangeable. Thus R^2 for 0·05 significance is $F'/[(\frac{N-k-1}{k}) + F']$ where F' is the F value for 0·05 significance with k and N–k–1 degrees of freedom. For a two stage regression as in the present case, $k=2$ and with N the number of cases, the previous expression becomes $F'/(\frac{N-3}{2} + F')$. Hence it is possible to scale the variation spectrum and determine immediately whether there is any significant periodicity. (d) incomplete data sets can be used without recourse to substituted values. This is an important advantage over autocorrelations in the case of Site 3. (e) as lags increase, autocorrelations involve fewer determinations and are consequently prone to increasing inaccuracies; this does not apply to R^2 determinations. Trials with the present data showed that autocorrelations and R^2 determinations gave different optimal wavelengths, and for the above reasons, R^2 was preferred.

Computations are not difficult and present results were obtained by a programme written for the Texas Instrument TI 59 with printer. This gave the regression parameters of the following equation:

$$y=\tfrac{1}{2}A^{\circ} + A\cos(2\pi t/T) + B\sin(2\pi t/T).$$

In this equation $\frac{1}{2}A^{\circ}$ is the estimated mid point of the oscillating curve; also from this equation C the half amplitude of the curve ($= \sqrt{A^2 + B^2}$) is obtained and also the estimated time of maximum values.

Based on early calculations, species data were given a 4·5th root transformation; this approximates to that required to give zero moment coefficients of skewness. For all species-in-sites which show significant periodicities, results are given in Table 5. Optimal wavelengths are to the nearest 0·1 month and three broad groups are apparent; much greater than 12 months *(Balanus* and *Bugula* in Site 1, and *Dryopoides* in Site 3); about 12 months (range 9·3–15·0) with ten cases; much smaller than 12 *(Electra* and *Ascidia* in Site 1 and *Tubularia* in Site 3).

If a roughly annual cycle is regarded as normal, then four of the 'abnormal' cases are in Site 1. Hints of abnormality in Site 1 were also obtained when ordinating the times, the data for the first year showing a particularly heterogeneous picture. This site is in a creek which was being deepened and widened to serve as the cooling water intake canal for the power station. This dredging activity was in progress until January 1976, and it is likely that the physical disturbance, change in hydrology and increased turbidity, contributed to biotic 'abnormality'. Results of the analyses conducted on the data from the second year (13 times, t_{12-24}) are given in Table 6. Comparison with Table 5 shows that now only two species *(Bugula* and *Hippodiplosia)* are 'abnormal'; in particular *Balanus* and *Electra* now show periodicities of about 12 months. The significance of the R^2 values has also been increased. Subsequently Site 1 data from t_{1-11} have been disregarded.

Two species-in-sites have short wavelengths: *Hippodiplosia* in Site 1 (4·5 months) and *Tubularia* in Site 3 (6·1 months). At this stage no further relationships to abiotic factors have been explored; possibly tidal amplitudes would repay attention. Most of the remaining species approximate to twelve monthly cycles.

To apply the present approach to abiotic data, these should be normally distributed. Perusal suggested normality for all except rainfall data where a 4th root transformation was required (and established via moment coefficients of skewness and kurtosis).

In Table 7 the results of the R^2 approach to data on temperature, chlorinity and rainfall are given. Temperatures for all sites were identical up to t_{18}; thereafter at Site 2 mostly higher temperatures (due to the thermal output from the Power Station) were recorded.

The R^2 values in Table 7 show significant cycles in order of significance with temperature > chlorinity > rainfall. Apart from chlorinities in Sites 2 and 3, there are approximately annual cycles throughout. Comparison of estimated times of maxima in Table 7 with those of Tables 5 and 6 would permit estimates of phase lag between abiotics and the species showing cyclical phenomena.

However the method here used is based on correlation coefficients, using appropriately transformed data and involved shifting the time base to obtain maximal agreement. Calculations were restricted to species with significant cycles and began on Site 2 since the data for this site is complete and the most extensive. Results given in Table 8 show 5/5 significant relationships with temperature, 3/5 with chlorinity and 0/5 with rainfall. Because of the low R^2 values for cyclical regressions using rainfall data (Table 7), no further correlations with rainfall were attempted.

Results from t_{12-24} for Site 1 are given in Table 9. Because of difficulties in shifting the time base when data are missing, data for Site 3 are restricted to t_{1-17} inclusive, with values substituted for those missing at t_2; for these the means of t_1 and t_3 were used. Results for Site 3 are also given in Table 9.

From Tables 8 and 9 collectively, it is clear that correlations with temperature are more significant than those with chlorinity — of 16 cases studied, 13 gave higher r values with temperature.

TABLE 5: SIGNIFICANT SPECIES PERIODICITIES, SITES 1, 2, AND 3

Species	Opt. W.L.	R^2	C	$\frac{1}{2}A^0$	Est. time of maxima (months)
SITE 1 (all times)					
Balanus	17·5	0·2950*	0·7170	2·0770	6·6, 24·1
Ficopomatus	11·1	0·5159***	1·2142	2·1163	5·7, 16·8
Bugula	19·9	0·6926***	1·2815	2·0005	9·8
Dryopoides	12·6	0·3287*	0·6234	0·4671	6·0, 18·6
Electra	5·7	0·3136*	0·5224	1·4205	1·3, 7·0, 12·7, 18·4, 24·1
Ascidia	5·0	0·3983**	0·7697	0·5067	2·5, 7·5, 12·5, 17·5, 22·5
SITE 2 (all times)					
Balanus	11·9	0·3857**	1·2974	2·2687	7·6, 19·5
Ficopomatus	12·3	0·6356***	1·6894	1·4654	9·2, 21·5
Bugula	12·7	0·3795**	0·6566	0·3601	5·2, 17·9
Electra	14·6	0·4864**	0·6963	0·8944	11·5
Tublaria	12·2	0·6523***	0·8774	0·5644	4·8, 17·0
SITE 3 (no data for t 2, 18, 19, and 24)					
Ficopomatus	11·9	0·6409***	1·4594	2·4570	4·3, 16·2
Dryopoides	18·3	0·4260**	0·6349	1·4486	9·2
Electra	15·0	0·5713***	0·9462	1·2508	11·8
Tubularia	6·1	0·3643*	0·5701	0·3762	6·0, 12·1, 18·2
Plumularia	13·3	0·4629**	0·7064	0·5897	7·7, 21·0

* Significant at 0·05 level
** at 0·01 level
*** at 0·001 level

TABLE 6: SIGNIFICANT SPECIES PERIODICITIES, SITE 1, TIMES 12–24

Species	Opt. W.L.	R^2	C	$\frac{1}{2}A^0$	Est. time of maxima (months)
Balanus	13·8	0·9227***	0·9992	2·0392	22·2
Ficopomatus	10·7	0·7879***	1·5939	1·7310	21·4
Bugula	ca 18	0·6419***	(not calculated W.L. "too long")		
Dryopoides	11·1	0·6933***	0·9176	0·7435	19·2
Electra	10·8	0·7375***	0·7002	1·4855	22·6
Hippodiplosia	4·5	0·5038*	0·7918	1·5361	12·6, 17·1, 21·6
Crassostrea	10·3	0·6546**	1·3351	0·9665	20·6

* Significant at 0·05 level
** at 0·01 level
*** at 0·001 level

TABLE 7: PERIODICITY OF ABIOTIC DATA, SITES 1–3

	Opt. W.L.	R^2	C	$\frac{1}{2}A^0$	Est. time maxima (mths)
Temperature Site 1*	13·1	0·9481	5·7178	25·2595	9·5, 22·6
Site 2†	12·1	0·8369	5·5865	23·5027	9·3, 21·4
Site 3†	12·1	0·9188	5·2060	23·0998	9·2, 21·3
Chlorinity Site 1*	11·4	0·8509	2·0086	18·7836	10·3, 21·7
Site 2†	18·5	0·5200	4·0574	15·4178	0·9, 19·4
Site 3†	18·5	0·5227	3·4236	12·9209	0·9, 19·4
Rainfall‡ Sites 2&3†	13·3	0·4745	0·7301	2·7846	12·2
Site 1*	12·9	0·4491	0·7000	2·7496	9·7

* Times 12–24
† all times
‡ 4th root transformation

TABLE 8: CORRELATION BETWEEN CYCLICAL SPECIES AND ABIOTIC FACTORS, SITE 2

Species	Temperature r	Temperature Time shift	Chlorinity r	Chlorinity Time shift	Rainfall r	Rainfall Time shift
Balanus	0·6092	3	−0·4722	0	0·2984†	0
Ficopomatus	0·8165	2	−0·4195	−1	0·3448†	0
Bugula	−0·5151	4	0·2701†	5	0·4091†	−1
Electra	0·5390	2	−0·3798†	−1	0·2860†	−4
Tubularia	−0·7271	3	0·4253	2	0·1858†	0

† Non significant correlations

In general there are positive correlations with temperature, with *Bugula* and *Tubularia* in Site 2 the only exceptions. Again with two exceptions (*Dryopoides* in Site 1 and *Tubularia* in Site 3) there is a positive shift i.e. species reach their maximum populations some months after the temperature maximum. The average shift for the significant cases in 2·43 months. The average time of the first temperature peaks being 9·33 (Jan. 1976) gives the 'average species' peak at $t_{11·76}$ (April 1976). Using the average time of the second temperature peaks (i.e. 21·77, Jan. Feb. 1976) an 'average species' peak at $t_{24·20}$ (April 1977) is obtained.

Comparing shifts in sites using the two cyclical species common to all sites (*Ficopomatus* and *Electra*) gives average shifts of 3 months for Site 1, 2 months for Site 2 and 3 months for Site 3; these differences are negligible. Comparing the two species occupying the three sites, gives averages of 2·7 for both *Ficopomatus* and *Electra*.

Of the 10 cases with significant r values with chlorinity, 8 have negative correlations, the exceptions being *Dryopoides* in Site 1 and *Tubularia* in Site 2. Disregarding these two species, the average time shift in significant cases is 0·63 months, implying that population peaks approximately coincide with salinity minima.

ANALYSIS OF ALGAL BIOMASS DATA

The algal biomass data from the upper surface of the plates at Site 2 are given in Table 10. Because of the considerable variation in the data, monthly means of the biomass were used to determine whether any relationship to abiotics could be detected. Initially a linear relationship between algal biomass and aboitics was assumed and regression analyses indicated that for chlorinity the relationship was not significant (r = 0·50) and no other relationship could be detected.

TABLE 9: CORRELATION BETWEEN CYCLICAL SPECIES AND ABIOTIC FACTORS, SITES 1 AND 3

Species	Temperature r	Temperature Time shift	Chlorinity r	Chlorinity Time shift
Site 1 (t12–24)				
Balanus	0·8795	3	−0·6000	1
Ficopomatus	0·8085	3	−0·7395	1
Dryopoides	0·8346	−1	0·6860	1
Electra	0·7018	3	−0·3942†	2
Hippodiplosia	0·5314	3	−0·2090†	2
Crassostrea	0·7844	2	−0·6202	−2
Site 3 (t1–17)				
Ficopomatus	0·8195	3	−0·5765	2
Dryopoides	0·6043	1	−0·6411	1
Electra	0·6089	3	−0·6203	3
Tubularia	0·3664†	−2	−0·4202†	1
Plumularia	0·3960†	0	0·1381†	1

† Non significant correlations

TABLE 10: ALGAL BIOMASS FROM UPPER SURFACES OF PLATES, SITE 2

Month	Biomass* 1975	1976	1977	Mean
January	—	49·0	206·2	127·6
February	—	150·3	0	75·2
March	—	133·3	36·5	84·9
April	—	48·9	0	24·5
May	963·6	108·2	78·6	383·5
June	615·0	387·2	419·3	473·8
July	444·2	301·8	824·6	523·5
August	222·1	304·1	936·2	487·5
September	225·5	336·0	355·4	305·6
October	96·8	0	717·5	271·4
November	118·5	228·9	—	173·7
December	92·3	111·6	—	102·0

* grams dry weight/m^2

For temperature r = -0·91, significant at 0·001 level, and the regression was biomass (g) = -3·50 (temperature) + 105·3. These data show a much closer relationship of algal biomass to temperature than to chlorinity. The generally greater variation in chlorinity may be responsible for the low r values.

LONG-TERM PLATES

Two sets were available from Auckland Creek and the Calliope River respectively, and analyses of each follows the techniques for the short-term plates except that no species were eliminated. Times were coded 1–6, species were coded 1–14 for Auckland Creek and separately 1–6 for the Calliope River.

TABLE 11: SPECIES GROUPINGS AND ABUNDANCE ON LONG-TERM PLATES, SITES 1 AND 2

Species	Code Number	Species Group*	Age of plates in months 1(t_1)	7(t_2)	8(t_3)	9(t_4)	10(t_5)	11(t_6)
Auckland Ck								
Tubularia crocea	4	I	16	8				
Balanus amphitrite	1		3		1			
Bugula neritina	3		44	4			2	
Electra cf. *anomala*	6		12					
Microcosmus australis	12	II			1			
Plumularia sp.	7	III		1		3		2
Ascidia sydneyensis	9			5	1	3	2	2
Polyandracarpa rhizoma	8			65	69	106	82	308
Bugula cf. *stolonifera*	2		5	1	5	13	7	13
sponge I	11			2	11	8	3	8
Hippodiplosia sp. A	5	IV	6		6	9	21	6
Branchiomma sp.	10				1	2	2	1
ascidian sp.	13					3	2	
Crassostrea cucullata	14	V						4
Calliope R.			1(t_1)	3(t_2)	4(t_3)	11(t_4)	12(t_5)	23(t_6)
Plumularia sp.	3	I	10					
Balanus amphitrite	1	II	173	24	22	13	5	12
Ficopomatus uschakovi	2		190	11	7	5	23	17
Electra cf. *anomala*	5		3	1				
Crassostrea cucullata	4	III	6	23	10	10	16	20
Modiolus auriculatus	6	IV					14	20
BIOMASS (g)			73·2	180·0	416·8	468·8	516·8	244·1

*From heirarchical classification

Auckland Creek Data (Site 1)

To obtain moment coefficients of skewness of 0·5, the modal transformation for times was a 5th root and for species a 1st root (ie. untransformed data). Results of the classifications are given in Figs. 4 and 5 respectively. The former shows 'chaining', no groupings and suggests successive and sequential changes. The latter was resolved into five groups (I–V) of which two are isolated species *(Microcosmus* and *Crassostrea)*. In Table 11 the results are given as a two-way coincidence table, with inclusion of species and code numbers.

Considering the species classification (Fig. 5) species group I contains species present in largest numbers at t_1 (the biotically most isolated time) and either not present later *(Electra)* or present at only the first two times *(Tubularia)* or intermittently present later *(Balanus, Bugula neritina)*. They can be regarded as the 'pioneer' community. Species group II can be neglected. Species group III contains species present from t_2 onwards and can be regarded as the 'stable' community. Species group IV attains maximum values in t_{4-5}; they may be either seasonal species or may indicate a seral stage to a later 'climax'. Species group V *(Crassostrea)* occurred only at t_6, and on the basis of other observations in the area, is considered to be an important climax species.

The difficulties caused by the absence of groupings in the times classification (Fig. 4) were partly resolved by determining inter-time coefficients (using 5th root transformations). There are significant correlations between all pairs of t_{3-6}. These times can be regarded as delimiting the climax state.

Calliope River Data (Site 2)

To obtain moment coefficients of skewness of 0·5, the modal transformation for times and for species is a 1st root transformation (i.e. no transformation). Results of classifications gave groupings in both cases — these are shown X on Figs. 6 and 7.

The two-way table (Table 11) shows that species group I *(Plumularia)* is an early transient or pioneer species; species group II contains species present in greatest numbers in t_1, and they either drop out soon *(Electra)* or persist *(Balanus* and *Ficopomatus)*; species group III *(Crassostrea)* is present throughout in substantially similar numbers while species group IV *(Modiolus)* only appears in later plates.

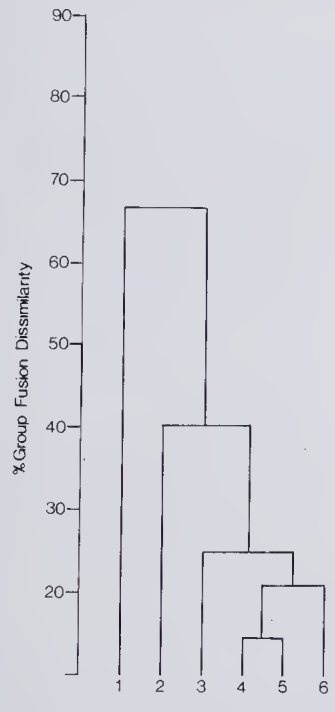

Fig. 4: Dendrogram of times classification from Auckland Creek long-term plates.

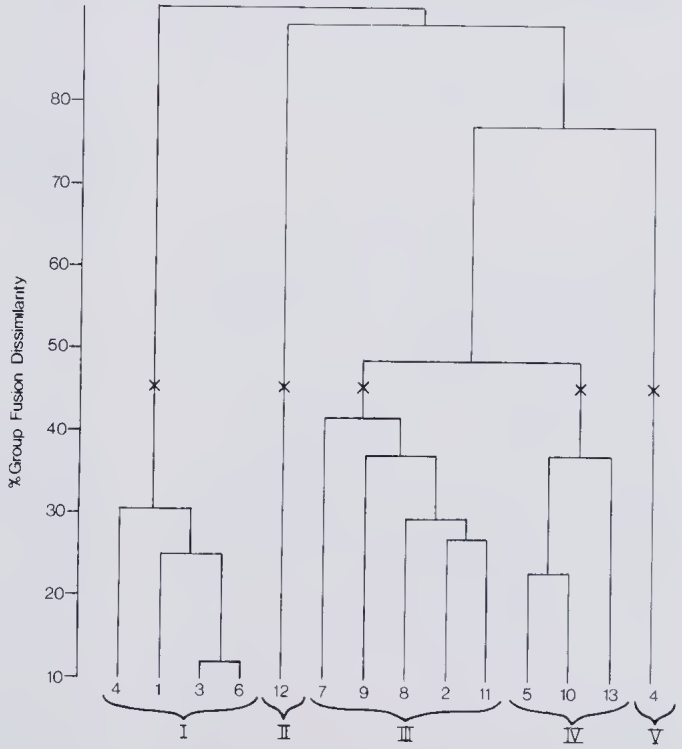

Fig. 5: Dendrogram of species classification from Auckland Creek long-term plates. X indicates species-groups accepted.

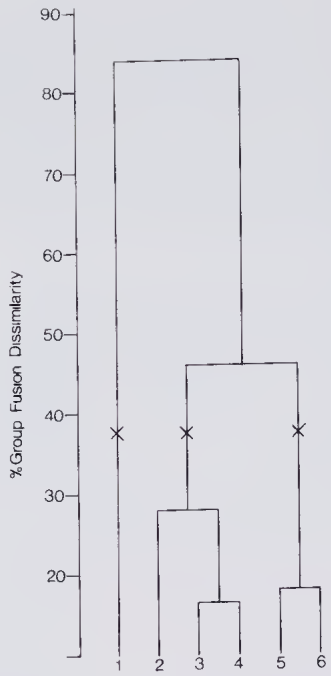

FIG. 6: Dendrogram of times classification from Calliope River long-term plates. X indicates times-groups accepted.

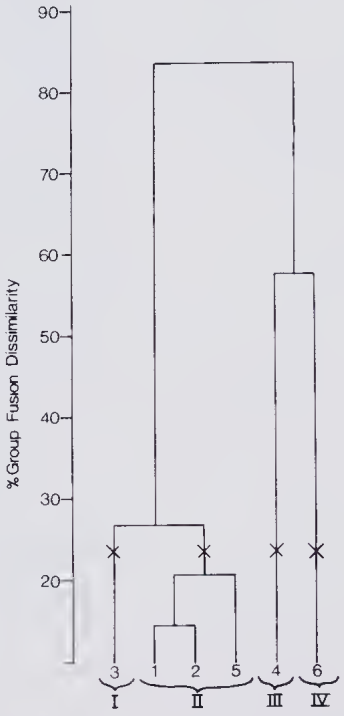

FIG. 7: Dendrogram of species classification from Calliope River long-term plates. X indicates species-groups accepted.

The first time group (t_1) is biotically the most isolated, the second (t_{2-4}) is characterised by *Balanus, Ficopomatus* and *Crassostrea,* while the third group (t_{5-6}) is additionally characterised by *Modiolus.*

Intertime correlation coefficients showed significant positive correlations between pairs of t_{2-4} and also between t_{5-6}. On this basis, t_{2-4} delimits a seral stage and t_{5-6} the climax.

Differences between the Auckland Creek and Calliope River will be noted; these are commented on below.

DISCUSSION

Little data on fouling organisms in Australasian waters is available and this is mostly from temperate waters (Allen and Wood 1950, Allen 1950, Skerman 1960, Straughan 1968, Wisely 1958a, b, 1959). While considerable overseas data is available on subtidal fouling organisms (Aleem 1957, Graham and Gay 1945, Haderlie 1968, Scheer 1948), most of these studies have not used detailed numerical analysis, or have used only binary data (e.g. McCain 1975).

Despite the subtropical estuarine setting of the present study, considerable generic similarity is found with the fouling organisms in Sydney (Wisely 1959) and Auckland (Skerman 1959). However caution must be exercised in comparing such areas for as the present data show, considerable variation exists from one sampling station to another. Site 1, situated in Auckland Creek (Fig. 1), significantly differs from Sites 2 and 3 in the Calliope River on the basis of (i) the number of species, (ii) the paired *t*-tests of individual species occurrence (Table 2) and (iii) the mean number of individuals of each species (Tables 3 and 4). Whether these differences result from abiotic factors or the proximity of mature adults is not known; however there are indications in the data (Tables 5 and 6) that physical disturbance at Site 1 is responsible for obscuring otherwise periodic settlement.

Nevertheless a group of species emerges which regularly occupies the short-term plates i.e. *Balanus, Ficopomatus* and *Electra.* These three species are the most numerous on the short-term plates and occur throughout the year. Other accompanying species do so only for certain periods of the year (Fig. 8).

The relationship between settlement and abiotic factors indicates the correlations are strongest with temperature, less so with chlorinity and are further reduced with rainfall. The algal biomass data from Site 2 shows identical relationships. This order of correlation is not unexpected since in an estuary with a large catchment area, chlorinity

will be more variable in the short-term than temperature, and the relationship of chlorinity and rainfall will be modified by the intensity and duration of rainfall, especially where extensive salt flats occur (Saenger and Robson 1977). Of those species showing approximately twelve monthly cycles (Tables 8 and 9), maximum settlement occurs about 2·7 months after the temperature maximum i.e. around April. In relation to chlorinity, maximum settlement in significant species occurs around the salinity minimum.

Classification of short-term plates gave time-groups that made little conceptual sense. It did emphasise that three species *(Balanus, Ficopomatus,* and *Bugula)* are regular colonisers of the short-term plates. Classification of the long-term plate data however indicated that these three species together with other less numerous ones, formed the 'pioneer' phase using one set of data (Auckland Creek) and were also present in largest numbers in the one month plates at the second (Calliope River). The two sets gave different 'climax' communities and two points require emphasis. Firstly, the time of initiation and collection has a bearing on the 'pioneer' species composition. For example, the 1-month old plate from Auckland Creek represents a winter plate and consequently *Ficopomatus* is absent and *Tubularia* is present in relatively large numbers (Fig. 8). Similarly the 1-month old plate from the Calliope River is an autumn plate and consequently *Crassostrea* is present (Fig. 8). Secondly, while the 23-month old plate from the Calliope River is termed a climax, it is only partly so. When the fouling community matures on a plate, it attains a thickness of approximately 2·5 cm, and with water movement and the death of underlying organisms, small patches of the entire community break off (with the consequent reduction in biomass — Table 11). The 'pioneer' species colonise these newly-formed, almost bare patches and a mosaic of different aged growth results. Consequently 'pioneer' species are found on mature plates although not strictly in the 'climax' phase. This type of 'patch-climax' is the common covering on natural substrates in the study area.

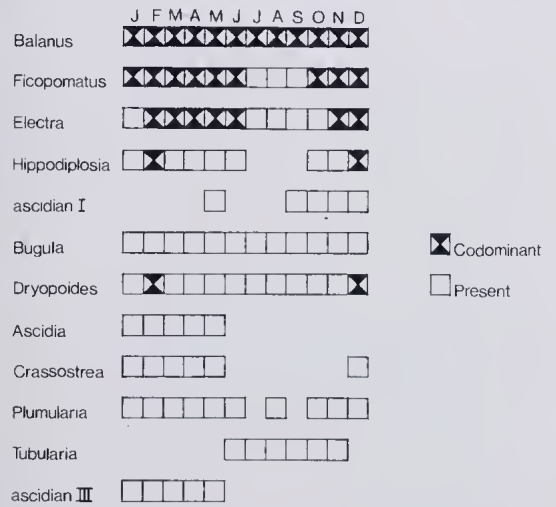

FIG. 8: Seasonal occurrence of sessile colonisers from short-term plates at all sites from May 1975 to May 1977.

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